CLAIMS

What is claimed is:

1. An apparatus for generating return-to-zero (RZ) optical pulses corresponding to an information signal, comprising:

a phase modulator for causing a phase change in an optical carrier signal responsive to a transition in a driving signal derived from the information signal; and

an interferometer coupled to receive an output of said phase modulator, said interferometer causing a fixed time delay between first and second signals derived from said output of said phase modulator, said fixed time delay being selected such that said first and second signals destructively interfere when no phase change is occurring in said output of said phase modulator and such that said first and second signals do not destructively interfere when said phase change does occur, an output of said interferometer comprising RZ optical pulses corresponding to said transitions in said driving signal.

2. The apparatus of claim 1, wherein said fixed time delay is set to an integer multiple of a period of the optical carrier signal, and wherein said interferometer output corresponds to a subtractive combination of said first and second signals.

3. The apparatus of claim 1, wherein said fixed time delay is set to an integer multiple of a period of the optical carrier signal plus one-half of said period, and wherein said interferometer output corresponds to an additive combination of said first and second signals.

4. The apparatus of claim 1, wherein said driving signal and said information signal are electrical signals.

5. The apparatus of claim 1, further comprising a differential encoder for receiving said information signal and generating said driving signal therefrom, said output of said interferometer having a binary pattern equal to a binary pattern of said information signal.

6. The apparatus of claim 5, said RZ optical pulses at said output of said interferometer having an induced frequency shift, said apparatus further comprising a phase modulating element at the output of said interferometer for imposing a compensating frequency shift on said RZ optical pulses, said compensating frequency shift being opposite in sign and substantially equal in magnitude to the induced frequency shift.

7. The apparatus of claim 6, wherein said phase modulator, said interferometer, and said phase modulating element are integrated onto a common substrate having a material system selected from the group consisting of: lithium niobate, semiconductor, InP, and GaAs.

8. The apparatus of claim 6, said driving signal and said information signal being electrical signals, said phase modulating element being driven by a first electrical signal derived from said driving signal.

9. The apparatus of claim 8, further comprising:

an electrical splitter for splitting said driving signal into second and third electrical signals;

an electrical delay element for delaying said third electrical signal with respect to said second electrical signal by an amount substantially equal to said fixed time delay of said interferometer; and

an electrical combining element for combining said second and third electrical signals to form said first electrical signal.

10. The apparatus of claim 1, wherein said driving signal is proportional to said information signal, said output of said interferometer having a binary pattern equal to a differentially encoded version of a binary pattern of said information signal.

11. The apparatus of claim 1, further comprising:

an optical source for providing said optical carrier signal at a carrier frequency; and

a feedback control circuit for precisely regulating either or both of (i) said fixed time delay of said interferometer, and (ii) said carrier frequency of said optical source.

12. The apparatus of claim 11, said feedback control circuit comprising:

a detector coupled to an auxiliary output of said interferometer, said detector measuring an average optical power at said auxiliary output; and

a control circuit coupled to said detector and to a fixed time delay element of said interferometer, said control circuit manipulating either or both of said fixed time delay and said carrier frequency such that said average optical power is maintained at an extremum.

13. The apparatus of claim 11, said optical carrier signal being polarized at a first polarization angle, said feedback control circuit comprising:

a coupler for tapping a pilot beam from said optical carrier signal prior to phase modulation of said optical carrier signal;

a 90-degree rotating element coupled to said coupler for causing said pilot beam to be at a second polarization angle that is 90-degrees from said first polarization angle;

a first polarization beamsplitter positioned between said phase modulator and said interferometer for combining said pilot beam with said phase modulator output, said pilot beam not interacting with said phase modulator output in said interferometer due to said 90-degree polarization difference, said output of said interferometer comprising said pilot beam at said second polarization angle and said RZ optical pulses at said first polarization angle, said pilot beam having an average power level that is at an extremum when said fixed time delay of said interferometer is at an optimal value;

a second polarization beamsplitter for receiving said interferometer output and extracting said pilot beam therefrom;

a detector coupled to said polarization beamsplitter for receiving said pilot beam and measuring said average power level thereof; and

a control circuit coupled to said detector and to a fixed time delay element of said interferometer, said control circuit manipulating either or both of said fixed time delay and

said carrier frequency such that said average optical power of said pilot beam is maintained at said extremum.

14. The apparatus of claim 1, wherein said fixed time delay is set approximately equal to an average duration of said transitions of said driving signal.

15. The apparatus of claim 1, wherein said phase modulator and said interferometer are integrated onto a common substrate having a material system selected from the group consisting of: lithium niobate, semiconductor, InP, and GaAs.

16. The apparatus of claim 15, further comprising a folded waveguide structure formed at an edge of said common substrate for coupling said interferometer to said phase modulator.

17. The apparatus of claim 15, said interferometer being a Michelson interferometer, said interferometer comprising:

an optical coupler;

a first arm between said optical coupler and a first mirror formed along a first edge of said substrate; and

a second arm between said optical coupler and a second mirror formed along a second edge of said substrate;

wherein said first and second edges are positioned with respect to said optical coupler so as to achieve a predetermined path difference between said first arm and said second arm corresponding to said fixed time delay.

18. The apparatus of claim 15, said common substrate being a semiconductor substrate, further comprising a variable-gain optical element integrated onto said common substrate, said variable-gain optical element comprising a semiconductor optical amplifier having a gain medium that is excited by lasing fields oriented in a direction different than a direction of signal propagation therethrough.

19. A method for generating return-to-zero (RZ) optical pulses corresponding to an information signal, comprising:

generating a driving signal from said information signal, said driving signal having two or more levels, said driving signal having level transition intervals of finite duration;

generating a phase-modulated optical signal from an optical carrier signal by causing phase changes therein during said level transition intervals of said driving signal;

generating first and second optical signals from said phase-modulated optical signal, said second signal being a substantially identical but delayed version of said first signal, said second signal being delayed with respect to said first signal by an unmodulated, predetermined, fixed time delay τ; and

combining said first and second optical signals to produce a resultant optical signal;

wherein said fixed time delay τ is selected such that said first and second optical signals destructively combine when no phase change is occurring in said phase-modulated optical signal, and such that said first and second optical signals do not destructively interfere when said phase change does occur, whereby said resultant optical signal comprises RZ optical pulses during said level transition intervals of said driving signal.

20. The method of claim 19, wherein said fixed time delay is an integer multiple of a period of the optical carrier signal, and wherein said step of combining comprises the step of forming a subtractive combination of said first and second optical signals.

21. The method of claim 19, wherein said fixed time delay is an integer multiple of a period of the optical carrier signal plus one-half of said period, and wherein said step of combining comprises the step of forming an additive combination of said first and second optical signals.

22. The method of claim 19, wherein said driving signal is generated by differentially encoding said information signal, said RZ optical pulses having a binary pattern equal to a binary pattern of said information signal.

23. The method of claim 22, said RZ optical pulses having an induced frequency shift, said method further comprising imposing a compensating frequency shift on said RZ optical pulses, said compensating frequency shift being opposite in sign and substantially equal in magnitude to the induced frequency shift.

24. The method of claim 23, wherein said driving signal and said information signal are electrical signals, and wherein imposing a compensating frequency shift comprises:

splitting the driving signal into first and second electrical signals;

delaying the second electrical signal with respect to the first electrical signal by an amount substantially equal to the fixed time delay τ; of said interferometer;

combining the first and second electrical signals to form a third electrical signal; and

phase-modulating said RZ optical pulses with a phase modulator driven by the third electrical signal.

25. The method of claim 19, wherein the driving signal is proportional to the information signal, the RZ optical pulses having a binary pattern equal to a differentially encoded version of a binary pattern of the information signal.

26. The method of claim 19, further comprising precisely regulating either or both of (i) said fixed time delay τ, and (ii) a carrier frequency of said optical carrier signal to an optimal value.

27. The method of claim 26, further comprising:

measuring an average optical power of a complementary resultant signal associated with said step of combining; and

manipulating either or both of said fixed time delay τ and said carrier frequency such that said average optical power of the complementary resultant signal is maintained at an extremum.

28. The method of claim 26, the optical carrier signal being polarized at a first polarization angle, further comprising:

tapping a pilot beam from the optical carrier signal prior to said step of generating a phase-modulated optical signal;

rotating the pilot beam to a second polarization angle that is 90-degrees from the first polarization angle;

combining the pilot beam with said phase-modulated optical signal prior to said step of generating first and second optical signals, the resultant optical signal comprising the pilot beam at the second polarization angle and the RZ optical pulses at the first polarization angle;

extracting the pilot beam from the resultant optical signal;

measuring an average power level of the pilot beam; and

manipulating either or both of said fixed time delay τ and said carrier frequency such that the average optical power of the pilot beam is maintained at an extremum.

29. The method of claim 19, wherein the fixed time delay τ is set approximately equal to an average level transition interval of the driving signal.

30. An apparatus, comprising:

a first optical device having a first input for receiving an optical carrier signal, a second input for receiving a first voltage, and an output, said first optical device being capable of inducing a variable phase change in the optical carrier signal proportional to the first voltage for generating a phase-modulated optical signal at said output thereof;

a second optical device having an input for receiving the phase-modulated signal and an output, said second optical device being capable of splitting the phase modulated optical signal into first and second optical signals, the second optical device being capable of inducing a time delay between the first and second optical signals and providing a combination thereof at said output of said second optical device;

wherein the time delay induced by the second optical device is a fixed, predetermined, unmodulated time delay that is an integer multiple of one-half the period of the optical carrier signal;

wherein, when said first voltage is at a constant value, said output of said second optical device has a null amplitude; and

wherein, when said first voltage is experiencing a change as approximated over an interval equal to said time delay of said second optical device, said output of said second optical device has an active amplitude.

31. The apparatus of claim 30, further comprising:

an information signal input for receiving a binary information signal; and

a differential encoder having an input coupled to said information signal input and an output, said output being a binary signal having a finite transition time between levels, said output being coupled to said second input of said first optical device;

whereby said output of said second optical device comprises an RZ-formatted optical signal having a binary pattern equal to the binary pattern of said information signal, each active bit of the RZ-formatted optical signal having a total pulse width approximately equal to a sum of said time delay of said second optical device and said transition time of said output of said differential encoder.

32. The apparatus of claim 30, further comprising:

an information signal input for receiving a binary information signal, said information signal having finite transition times between levels, said information signal input being coupled to said second input of said first optical device, wherein said first voltage is proportional to said information signal;

whereby said output of said second optical device comprises an RZ-formatted optical signal having a binary pattern equal to the binary pattern of said information signal, each active bit of the RZ-formatted optical signal having a total pulse width approximately equal to a sum of said time delay of said second optical device and said transition time of said output of said differential encoder.

33. The apparatus of claim 30, wherein said first optical device comprises a phase modulator.

34. The apparatus of claim 33, wherein said second optical device comprises an interferometer.

35. An apparatus for generating return-to-zero (RZ) optical pulses corresponding to an information signal, comprising:

a differential encoder having an input for receiving the information signal and an output;

a first variable phase changing element having a first input for receiving an optical carrier signal, a second input coupled to the output of said differential encoder, and an output, said first variable phase changing element inducing a phase change that monotonically corresponds to a voltage at said second input;

an optical splitting element having an input coupled to the output of said first variable phase changing element, a first output, and a second output;

an optical combining element having a first input, a second input, and an output;

a first optical path between said first output of said optical splitting element and said first input of said optical combining element, said first optical path inducing a first fixed time delay therebetween;

a second optical path between said second output of said optical splitting element and said second input of said optical combining element, said second optical path inducing a second fixed time delay therebetween, wherein said first and second time delays differ by integer multiple of one-half the period of the optical carrier signal, said output of said optical combining element comprising the RZ optical pulses corresponding to the information signal.

36. The apparatus of claim 35, said RZ optical pulses at said output of said optical combining element having induced frequency shift, said apparatus further comprising:

a second variable phase changing element having a first input coupled to said output of said optical combining element, a second input, and an output, said second

variable phase changing element inducing a phase change that monotonically corresponds to a voltage at said second input;

an electrical compensating circuit having an input coupled to the output of said differential encoder and an output coupled to said second input of said second variable phase changing element, said electrical compensating circuit comprising:

an inverter having an input coupled to said differential encoder output, and an output;

an electrical splitting element having an input coupled to the output of said inverter, a first output, and a second output;

an electrical combining element having a first input, a second input, and an output, said output being coupled to said second input of said second variable phase changing element;

a first electrical path between said first output of said electrical splitting element and said first input of said electrical combining element, said first electrical path inducing a third fixed time delay therebetween;

a second electrical path between said second output of said electrical splitting element and said second input of said electrical combining element, said second electrical path inducing a fourth fixed time delay therebetween, wherein said third and fourth time delays differ by an amount approximately equal to said difference between said first and second time delays;

whereby said output of said second variable time delay comprises RZ optical pulses substantially equal to said RZ optical pulses at said output of said optical combining element but with substantially reduced frequency shift.

37. The apparatus of claim 36, wherein said differential encoder, said first variable phase changing element, said optical splitting element, said optical combining element, said first and second optical paths, said second variable phase changing element, and said electrical compensating circuit are integrated onto a common semiconductor substrate.

38. The apparatus of claim 37, further comprising a variable-gain optical element integrated onto said semiconductor substrate.

39. The apparatus of claim 38, said variable-gain optical element comprising a semiconductor optical amplifier having a gain medium that is excited by lasing fields oriented in a direction different than a direction of signal propagation therethrough.

40. The apparatus of claim 35, wherein said first variable phase changing element, said optical splitting element, said optical combining element, and said first and second optical paths are integrated onto a common substrate having a material system selected from the group consisting of: lithium niobate, semiconductor, InP, and GaAs.

41. The apparatus of claim 40, wherein said first variable phase changing element is coupled to said optical splitting element by a folded waveguide structure formed at an edge of said common substrate.

42. An integrated optical circuit for interferometrically redirecting an optical signal from propagation in a first direction on a first waveguide to propagation in a second direction on a second waveguide, the second direction being approximately opposite the first direction, the second waveguide being separated from the first waveguide by less than a minimum bending radius corresponding to a substrate upon which the integrated optical circuit is formed, the integrated optical circuit comprising:

an optical coupler having an input coupled to the first waveguide, an output coupled to the second waveguide, a first intermediate port, and a second intermediate port;

a first reflective surface formed on a first edge of the substrate;

a first interferometer arm coupled between said first intermediate port and said first reflective surface;

a second reflective surface formed on a second edge of the substrate; and

a second interferometer arm coupled between said second intermediate port and said second reflective surface;

wherein said first and second substrate edges are positioned with respect to said optical coupler such that an effective path length of said first interferometer arm differs from an effective path length of said first interferometer arm by a predetermined amount corresponding to a desired interferometric time delay.

43. The integrated optical circuit of claim 42, wherein said first and second substrate edges are substantially parallel to each other.

44. The integrated optical circuit of claim 43, wherein said first and second interferometer arms are substantially parallel to each other and to said first and second waveguides.

45. The integrated optical circuit of claim 44, wherein said first and second interferometer arms are separated by a distance not exceeding said minimum bending radius along their entire lengths.

46. The integrated optical circuit of claim 45, wherein said first and second substrate edges form a step-like indentation along a major edge of the substrate.

47. The integrated optical circuit of claim 45, wherein said substrate is lithium niobate, and wherein said minimum bending radius is approximately 1 cm.

48. The integrated optical circuit of claim 45, further comprising a resistive heating element positioned near said first interferometer arm for allowing fine-tuning of its effective path length.

49. The integrated optical circuit of claim 48, wherein said optical coupler, said first and second interferometer arms, and said first and second reflective surfaces form a Michelson interferometer.